

# Ridge correlation structure in high multiplicity pp collisions with CMS

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## Abstract.

Results on two-particle angular correlations are presented in proton-proton collisions at center of mass energies of 7 TeV, over a broad range of pseudorapidity and azimuthal angle. In very high multiplicity events at 7 TeV, a pronounced structure emerges in the two-dimensional correlation function for particle pairs with intermediate  $p_T$  of 1–3 GeV/c, in the kinematic region  $2.0 < |\Delta\eta| < 4.8$  and small  $\Delta\phi$ . This structure, which has not been observed in pp collisions before, is similar to what is known as the "ridge" in heavy ion collisions. It is not predicted by commonly used proton-proton Monte Carlo models and is not seen in lower multiplicity pp collisions. Updated studies of this new effect as a function of particle transverse momentum, rapidity and event characteristics are shown.

Long-range, near-side ( $\Delta\phi \approx 0$ ) ridge-like azimuthal correlations for  $2.0 < |\Delta\eta| < 4.8$  have recently been observed for the first time in high multiplicity pp collisions at  $\sqrt{s} = 7$  TeV [1]. The novel structure resembles similar features observed in relativistic heavy-ion experiments. This striking feature is most evident in the intermediate transverse momentum range of both  $1 < p_T^{\text{trig}} < 3$  GeV/c and  $1 < p_T^{\text{assoc}} < 3$  GeV/c. A steep increase of the near-side associated yield with multiplicity has been found in the data.

Following up the first observation of the ridge correlation structure in high multiplicity pp collisions at  $\sqrt{s} = 7$  TeV, new results are presented in this paper to study the detailed event multiplicity, transverse momentum and pseudorapidity gap ( $\Delta\eta$ ) dependence of the ridge effect using the full statistics data collected in 2010. With the nearly  $4\pi$  solid-angle acceptance of the silicon tracker and dedicated high multiplicity high-level trigger (HLT) setup, the CMS experiment has a unique capability in studying this novel effect [2].

The same analysis procedure, as used in the ridge measurement of the central heavy-ion collisions [3], is applied in order to make direct comparison to the heavy-ion results, for full details see [4]. The pp data used in this extended analysis are collected under almost the same condition as those used in the publication of the first pp ridge observation [1] with about a factor of 2 increase in statistics, 660K  $N \geq 110$  events.

The per-trigger-particle associated yield distribution of charged hadrons as a function of  $\Delta\eta$  and  $\Delta\phi$  in high multiplicity ( $N \geq 110$ ) pp collisions at  $\sqrt{s} = 7$  TeV with

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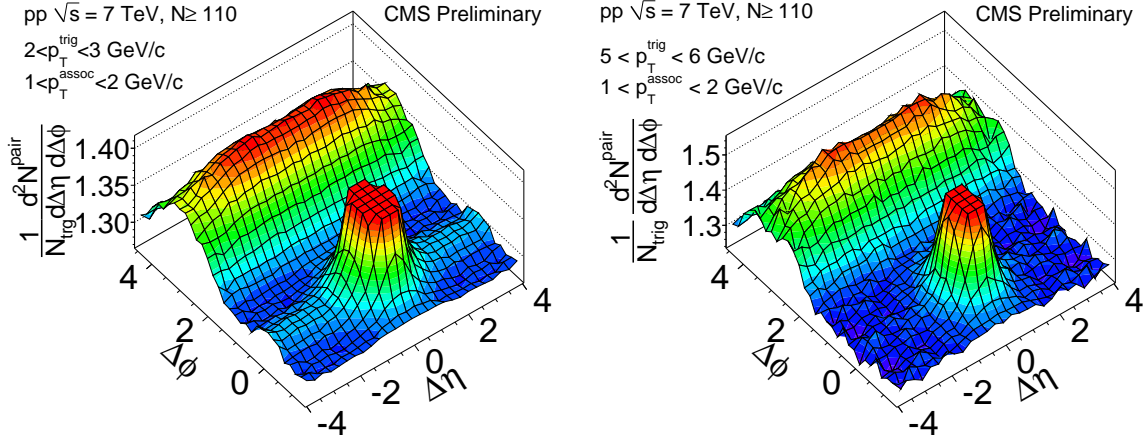


Figure 1: Two-dimensional (2-D) per-trigger-particle associated yield of charged hadrons as a function of  $\Delta\eta$  and  $\Delta\phi$  with jet peak cutoff for better demonstration of the ridge from high multiplicity ( $N \geq 110$ ) pp collisions at  $\sqrt{s} = 7$  TeV, for (a)  $2 < p_T^{\text{trig}} < 3$  GeV/c and  $1 < p_T^{\text{assoc}} < 2$  GeV/c and (b)  $5 < p_T^{\text{trig}} < 6$  GeV/c and  $1 < p_T^{\text{assoc}} < 2$  GeV/c

trigger particles with  $2 < p_T^{\text{trig}} < 3$  GeV/c and associated particles with  $1 < p_T^{\text{assoc}} < 2$  GeV/c is shown in Fig. 1 obtained with the full statistics data in 2010. The ridge-like structure is clearly visible at  $\Delta\phi \approx 0$  extending to  $|\Delta\eta|$  of at least 4 units as previously observed in Ref. [1]. However, at higher  $p_T^{\text{trig}}$  of 5–6 GeV/c as presented in Fig. 1, the ridge almost disappears. The absolute values of  $\Delta\eta$  and  $\Delta\phi$  are used in the analysis, thus the resulting distributions are symmetric about  $(\Delta\eta, \Delta\phi) = (0, 0)$  by construction.

In order to fully explore the detailed properties of both short-range jet-like correlations and long-range ridge-like structure, especially its dependence on event multiplicity, transverse momentum and  $|\Delta\eta|$ , the associated yield distributions are obtained in eight bins ( $2 \leq N < 35$ ,  $35 \leq N < 45$ ,  $45 \leq N < 60$ ,  $60 \leq N < 90$ ,  $N \geq 90$ ,  $N \geq 110$ ,  $N \geq 130$ ,  $N \geq 150$ ) of charged particle multiplicity and six bins (0.1–1, 1–2, 2–3, 3–4, 4–5 and 5–6 GeV/c) of particle transverse momentum. The 1-D  $\Delta\phi$  azimuthal correlation functions are calculated by integrating over the  $0.0 < |\Delta\eta| < 1.0$  and  $2.0 < |\Delta\eta| < 4.0$  region, defined as the jet region and ridge region, respectively.

The near-side (small  $\Delta\phi$  region) integrated associated yield is calculated for both jet and ridge regions relative to the constant background, details in Ref. [3]. Fig. 2 presents the resulting near-side associated yield as a function of  $|\Delta\eta|$  (in slices of 0.6 units) in high multiplicity ( $N \geq 110$ ) pp collisions at  $\sqrt{s} = 7$  TeV with trigger particles with  $2 < p_T^{\text{trig}} < 3$  GeV/c and associated particles with  $1 < p_T^{\text{assoc}} < 2$  GeV/c. The high multiplicity data exhibit a jet-like correlation peak in the yield for small  $|\Delta\eta|$  and show significant and roughly constant yield out to the highest  $|\Delta\eta|$  regions. This is qualitatively similar to what has been observed in central PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [3] but is completely absent in minimum bias pp collisions as well as pp MC models.

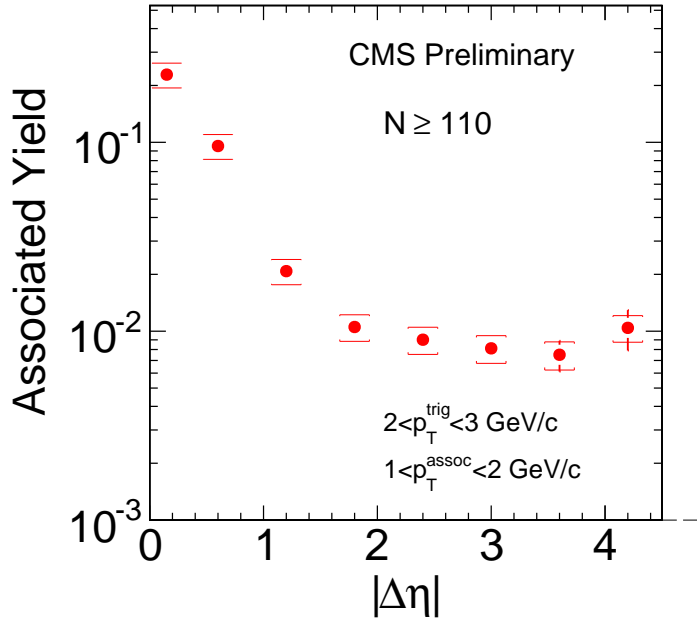


Figure 2: Integrated near-side ( $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$ ) associated yields for  $2 < p_T^{\text{trig}} < 3$  GeV/c and  $1 < p_T^{\text{assoc}} < 2$  GeV/c, above the minimum level found by the ZYAM procedure, as a function of  $|\Delta\eta|$  for the high multiplicity ( $N \geq 110$ ) pp collisions at  $\sqrt{s} = 7$  TeV. The statistical uncertainties are shown as bars, while the brackets denote the systematic uncertainties.

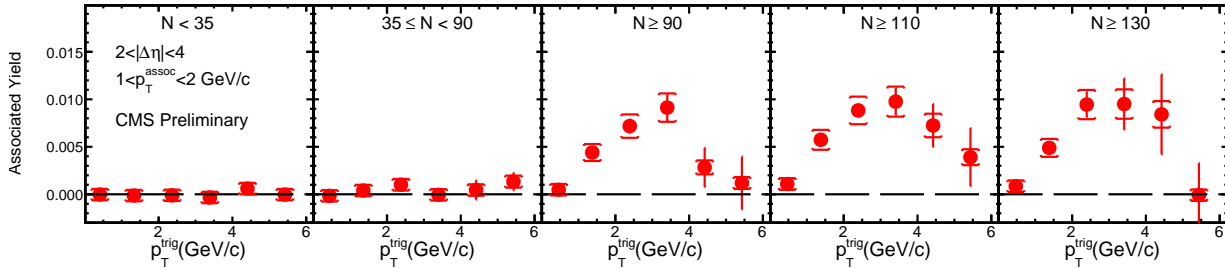


Figure 3: Integrated near-side ( $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$ ) associated yields for the long-range ridge region ( $2 < |\Delta\eta| < 4$ ) with  $1 < p_T^{\text{assoc}} < 2$  GeV/c, above the minimum level found by the ZYAM procedure, as a function of  $p_T^{\text{trig}}$  for five multiplicity bins ( $2 \leq N < 35$ ,  $35 \leq N < 90$ ,  $N \geq 90$ ,  $N \geq 110$ ,  $N \geq 130$ ) of pp collisions at  $\sqrt{s} = 7$  TeV. The statistical uncertainties are shown as bars, while the brackets denote the systematic uncertainties.

Figure 3 shows the integrated near-side associated yield of the ridge region correlations with  $1 < p_T^{\text{assoc}} < 2$  GeV/c (the  $p_T$  range where the ridge effect appears to be strongest) as a function of  $p_T^{\text{trig}}$  in five bins of event multiplicity. The ridge yield is

almost zero for the first two low multiplicity bins in Fig. 3. In the high multiplicity region ( $N \geq 90$ ), the ridge yield first increases steadily with  $p_T^{\text{trig}}$ , reaches a maximum around  $p_T^{\text{trig}} \sim 2\text{--}3$  GeV/c and drops at higher  $p_T^{\text{trig}}$ .

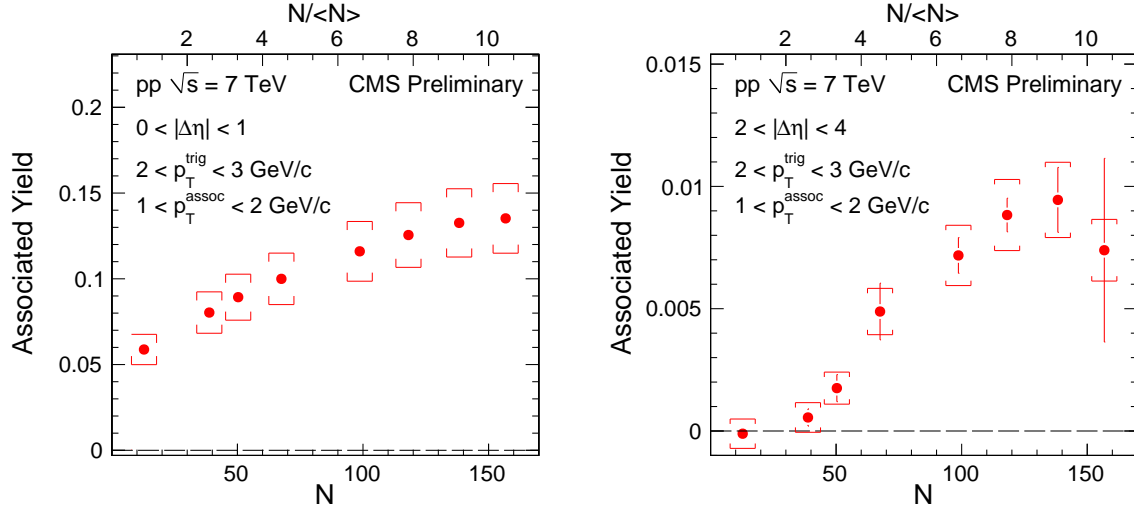


Figure 4: Integrated near-side ( $|\Delta\phi| < \Delta\phi_{\text{ZYAM}}$ ) associated yields for the short-range jet region ( $0 < |\Delta\eta| < 1$ ) and the long-range ridge region ( $2 < |\Delta\eta| < 4$ ), with  $2 < p_T^{\text{trig}} < 3$  GeV/c and  $1 < p_T^{\text{assoc}} < 2$  GeV/c, above the minimum level found by the ZYAM procedure, as a function of event multiplicity from pp collisions at  $\sqrt{s} = 7$  TeV. The statistical uncertainties are shown as bars, while the brackets denote the systematic uncertainties.

The multiplicity dependence of the near-side associated yield in the jet and ridge region is illustrated in Fig. 4 for one transverse momentum bin of  $2 < p_T^{\text{trig}} < 3$  GeV/c and  $1 < p_T^{\text{assoc}} < 2$  GeV/c, the  $p_T$  bin where the ridge effect appears to be strongest. The ridge effect gradually turns on with event multiplicity around  $N \sim 50\text{--}60$  and shows a tendency to saturate when it reaches  $N \sim 120$ , although this is not yet conclusive with current statistical and systematic uncertainties.

In summary, comprehensive studies of the ridge correlation structure in high multiplicity pp events, as a function of event multiplicity, particle transverse momentum and  $\Delta\eta$  using full statistics pp data in 2010, are presented in this paper, which provides further information on the properties of the novel ridge phenomena. This is an important step forward toward understanding the physical origin of the ridge in high multiplicity pp collisions and put additional constraints on various theoretical models.

## References

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- [2] CMS Collaboration, *JINST* **0803** (2008) S08004. doi:10.1088/1748-0221/3/08/S08004.
- [3] CMS Collaboration, [arXiv:1105.2438](#).
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